Attorney's Docket No. 01997-270001 / MIT 8554

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JUL -3 2002

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Applicant	: Erik R. Thoen et al.	Art Unit	: 2881
Serial No.	: 09/542,061	Examiner	: J. Menefee
Filed	: April 3, 2000		
Title	: SEMICONDUCTOR ELEMENTS FOR STABILIZING LASER OUTPUT		

Commissioner for Patents
Washington, D.C. 20231

SECOND AFFIDAVIT OF ERIK R. THOEN UNDER 37 C.F.R. § 1.131

I, Erik R. Thoen, declare as follows:

1.   I am the same Erik Thoen who executed the Affidavit of Erik R. Thoen Under Rule 37 C.F.R. sec. 1.131, executed October 2, 2001, and submitted with the Response dated October 4, 2001 ("my First Affidavit").

2.   I have read the Office Action mailed December 20, 2001, and the U.S. Patent No. 6,252,892 B1 to Jiang et al. ("the Jiang patent"), cited by the Examiner in the Office Action. The Jiang patent was filed on September 8, 1998.

3.   Our pending patent application includes two independent claims directed to producing non-linear increasing loss in a passive mode-locked laser system (claims 10, 26), and one independent claim directed to producing non-linear increasing loss in either a passively or actively mode-locked laser system (claim 1).

4.   Before September 8, 1998, I conceived of the invention of independent claims 1, 10, and 26, and reduced an embodiment to practice.

a)   Before September 8, 1998, co-inventors and I conceived a laser system with a pump, a gain medium producing radiation at an operative wavelength, and a reflector disposed along an optical path in the laser system's cavity, where the reflector includes layers of a first semiconductor material that act as a saturable absorber, and layers of a second semiconductor material that produces nonlinearly increasing loss to stabilize the mode-locked output of the laser system.

b)   This conception was recorded in my lab notebook. In my notebook, I calculated that a Bragg mirror having a particular InGaAsP/InP structure and an AR coating, when placed along an optical path in a laser system producing radiation at an operative wavelength of 1540 nm, would produce non-linearly increasing TPA loss, in addition to saturable absorption. These pages from my lab notebook were attached as Exhibit A to my First Affidavit. (The date was redacted from the notebook pages attached as Exhibit A. I represent that this redacted date is earlier than September 8, 1998.)

c)   Shortly after performing the above calculations, I measured the reflectivity of the InP InGaAsP Bragg reflector described in subparagraph (b) above using a Kerr-lens mode-locked laser system producing radiation at 1530 nm, with 150 fs pulses. The data showed saturable absorption and nonlinear increasing loss. A graph depicting this data was attached as Exhibit B to my First Affidavit. (I have redacted the date of the experiment from Exhibit B. I represent that this redacted date is earlier than September 8, 1998.)

d)   I believe the laser system I used in the experiment described in subparagraph (c) meets all the elements of independent claim 1. The laser system in the experiment defined a cavity, and produced radiation at an operative wavelength. The system included a mode-locking element configured to mode-lock output of the laser (the Kerr-lens), and a semiconductor element (layer of InP) that produced nonlinear increasing loss at the operative wavelength sufficient to enhance stability of the mode-locked output.
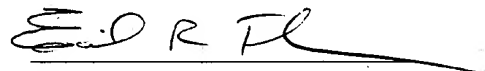
e)   I also believe my performance of the experiment described in subsection (c) meets all the elements of method claim 26, for the reasons discussed above in subparagraphs (c) and (d).

f)   After performing the experiment of subparagraph (c), I tested this same reflector in a laser system that was not Kerr-lens mode-locked, to demonstrate that the saturable absorption produced by the reflector in the experiment of subparagraph (c) could mode-lock the laser's output. Attached to this Affidavit as Ex. 1 are my lab notebook pages showing the results of this experiment. The first four pages of Ex. 1 are my analysis of the raw data, and the last four are graphs showing the data. As demonstrated clearly by the last two graphs, this laser system is mode-locked by the saturable absorption layers in the reflector at the same operative wavelength that produces nonlinear increasing loss. (The dates in Ex. 1 have been redacted. I represent that these dates are prior to September 8, 1998.)

g)   I believe that my experiment of subparagraph (f), in view of the data from the experiment of subparagraph (c), satisfies all the elements of claim 10. The experiment of subparagraph (d) included a pump, a gain medium that produced radiation at an operative wavelength, and a reflector disposed along an optical path in the laser system's cavity. The reflector included layers of a first semiconductor material (InGaAsP) that acted as a saturable absorber at the operative wavelength to mode-lock output of the laser, and one or more layers of a second semiconductor material (InP). As demonstrated by the data shown in experiment (c), the InP produces nonlinear increasing loss at the operative wavelength sufficient to enhance the stability of the mode-locked output.

5.   I affirm, under penalty of perjury, that all statements made herein are true, to the best of my knowledge, information and belief.
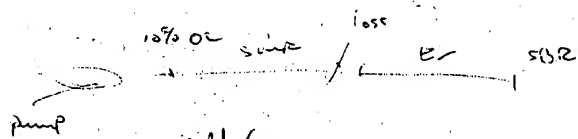
Dated: 6/13/02

Erik R. Thoen

TPA Effects

Saturation measurements
    various structures
    range of lenses   vary χ
    simple modelling
    mirror alone.)
Simple cavity

CW vs Fs ⟹ proof of
    mechanism.
NaCl vs OPO
on stretching

10% oc   surf   loss   Er   SBR

pump

add loss
identical single pass gain
different cavity config
only diff Er fibre — vs
                    consequences

demonstrate pulse limited
by TPA.
AC / spectrum.

disp shift   vs Surf
        soliton or no sol shaping

Phase Measurements
explanation of
        dynamics
relate to SOAs.
introduce χ's
sample w/ large
response.
Noncollinear
measurement
expectations based on
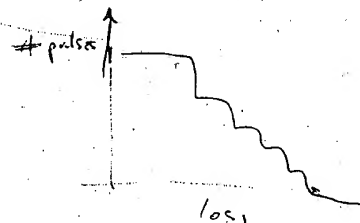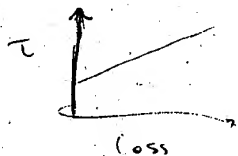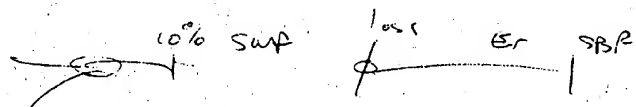SOAs but really CW
associated theory
paper
General dynamics
Done already
Need to relate to
lasing characteristic
Proton bombardment
changing time
const)

Absorber Design.

10% surf   loss   Er   SBR

1.3

τ

loss

A?

loss

pulse

loss

lower yield laser
low attenuator
2. Is pumping the
same as loss?

Investigate multiple pulsing
    previously w/ power dependence
Saturable Absorber Dynamics
    Varies pulse energy?
    high loss cases for waveguide
    investigate requirements
    vary through Q switch
                    Q sw modelocked
                        cw modelocked.
    illustrate continuous control of dynamics

Modelocking risetime
    In fiber?
    in fibre chopper?

New SBR IV A2   ●   t = 20 cm

I   Pout

100
200
300

The vac ... in λ w/
focus was of the same
as for the HR.

Here the time down. I
20 ut
~~as~~ observe QS ..~ QSML

On the rf spectrum analyzer

1.8 GHz

The air cavity forms a FP ~~....~~ filter
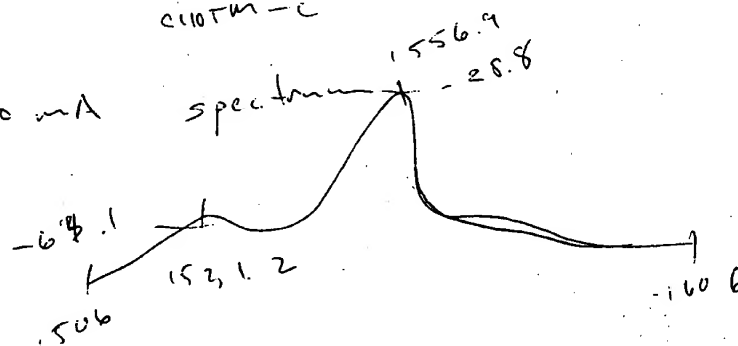of the modes

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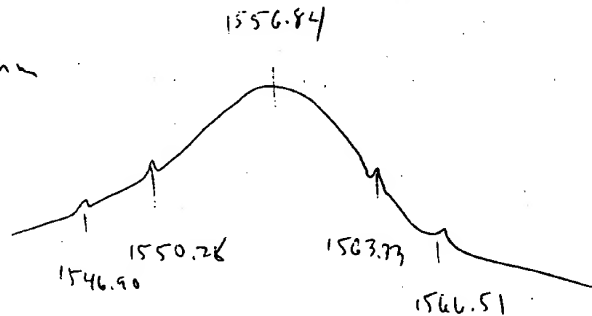changing to SBR III Resonant

SBR III R

C110TM-C

at 150 mA spectrum

1556.9
-28.8

-64.1

152, 1. 2

.506

-100 6

Saved in
98073101.05 <

Blow up (30 cm span)

1556.84

3dB 3.37 nm

98073162.05 <

1550.26   1503.73

1546.90

1566.51

Measuring the rep rate 42.234 458 MHz

-80-90 dB

-62.67 dB

- 67.33 dB

2 kHz span

120 Hz

127 Hz

- 80 dB

1 mHz
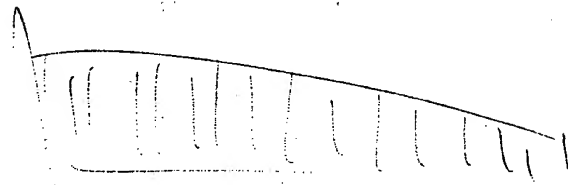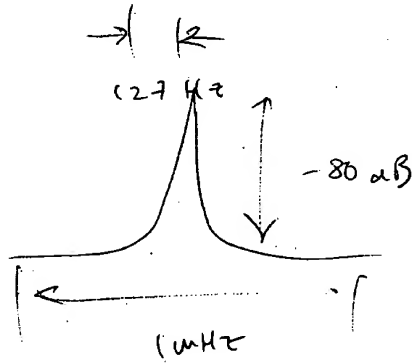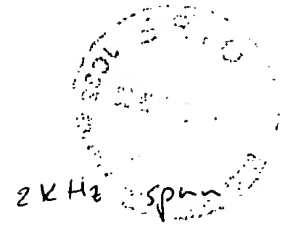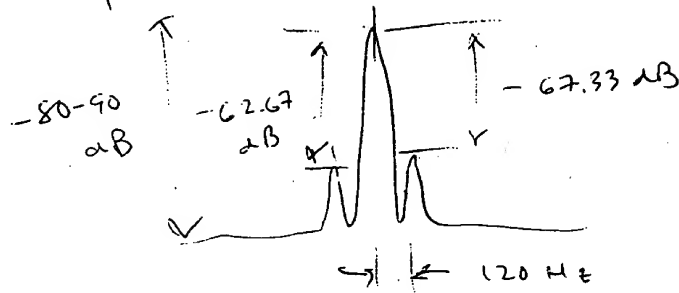
Modes locked to 2.9 GHz

2.8 GHz

Time domain
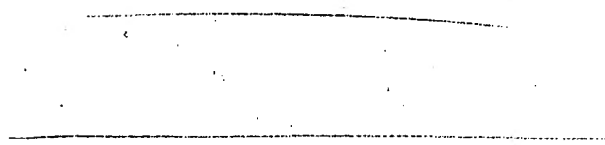
completely flat on a 1 ms time base

pulse width limited to detector BW

23.5 ns

QS

I	T_p
90	64 ms
100	55 ms
110	52 ms
120	46 ms
130	43 ms

CW   modelocking

$$125.5 - 100$$
$$125 - 164$$

Very sensitive to backreflections
measurements taken w/ FC connector screwed
in all the way.

Q S

I	T_p
170	36 ms
180	34 ms
220	30 ms
250	27.5 ms
700	25 ms

$$P_{in} T_{wdm} T_{oc} = P_{out}$$

$$P_{in} = \frac{P_{out}}{T_{wdm} T_{oc}} = \frac{P_{out}}{0.15}$$

CW

I	P_{out}	Calculated Intercavity Power	$E \left(\frac{\mu J}{cm^2} \right)$ = 6.3309 &
150 mA	0.49 mW	3.10 mW	73.91
140	0.43	2.72	64.85
130	0.38	2.41	57.46
160	0.55	3.48	82.97

↑
all seem to
make sens

Calculating the pulsewidth assuming transform limited pulses.

$$\Delta \tau \, \Delta \nu = 0.3148 \qquad \text{sech}$$

$$\nu = \frac{c}{\lambda} \qquad \frac{\partial \nu}{\partial \lambda} = \frac{c}{\lambda^2} \qquad \Delta \nu = \frac{c}{\lambda^2} \Delta \lambda$$

$$\Rightarrow \Delta \tau = \frac{0.3148 \, \lambda^2}{c \, \Delta \lambda}$$

$$\Delta \tau = \frac{0.3148 \, (1556.84 \times 10^{-9} \text{m})^2}{(3 \times 10^{8} \text{m/s})(3.37 \times 10^{-9} \text{m})} =$$

$$\Delta \tau = 754.7 \, fs$$

So at least it should be sub-picosecond.

Now let's try to obtain the other cavity parameters.

Estimate spot size   of output 1.1×10^{-3} m $= d$

Gaussian focussed spot diameter. $f = 6.24$ mm $= 6.24 \times 10^{-3}$ m

$$a = \frac{4 \lambda f}{\pi d} = \frac{4 (1556.84 \times 10^{-9} \text{m})(6.24 \times 10^{-3} \text{m})}{\pi (1.1 \times 10^{-3} \text{m})}$$

$$a = 1.1245 \times 10^{-5} \text{m} = 11.25 \, \mu\text{m} \leftarrow \text{very close to the l.l. modefield diameter}$$

Now the energy density
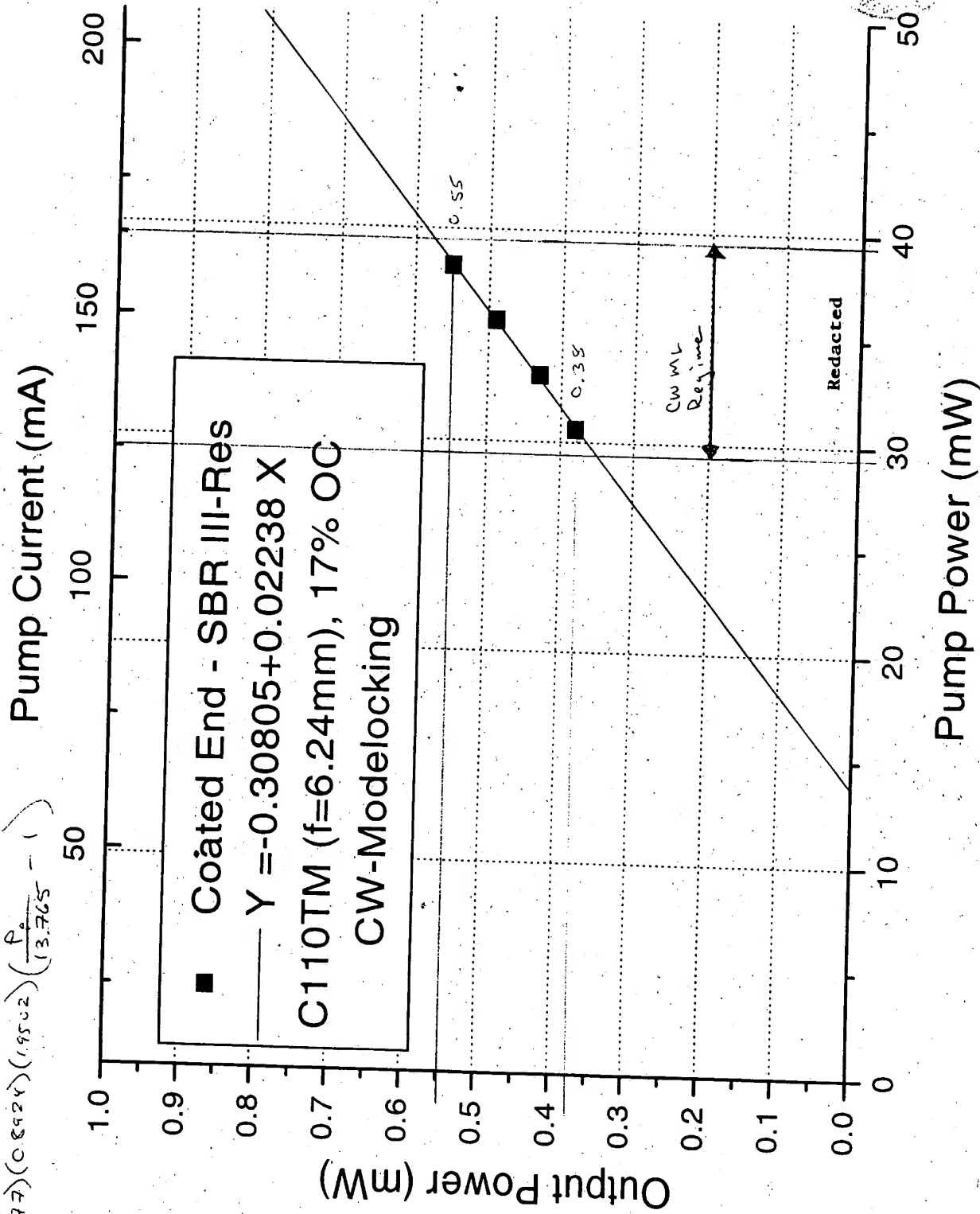
$$E = \frac{P_{av}}{f} \frac{1}{\pi \left(\frac{a}{2}\right)^2} = \frac{P_{av} \left(\frac{mJ}{s}\right)}{(42.234 \times 10^{6} \frac{1}{s})} \frac{1}{\pi \left(\frac{1.1245 \times 10^{-5} m}{2 \left(\frac{m}{100 cm}\right)}\right)^2} \left(\frac{1000 mJ}{mJ}\right)$$

$$= P_{av}(mW) \, 2.3843 \times 10^{5} \quad \left(\frac{mJ}{m^2}\right)$$

$$= P_{av}(mW) \, 23.843 \left(\frac{mJ}{cm^2}\right)$$

calculating on the previous page

Coated End - SBR III-Res

Y =-0.30805+0.02238 X

C110TM (f=6.24mm), 17% OC
CW-Modelocking

Pump Current (mA)

Pump Power (mW)

Output Power (mW)

CW ML Regime

Redacted

$P_{out} = T_{oc} \tau_{cavun} P_L \left(\frac{1}{\eta_{fac}} - () \right)$

$= (0.177)(0.6424)(.9502) \left(\frac{P_a}{(3.765} - () \right)$

Relax Osc Freq

Data: Data1_G
Model: $((r-1)/(Tc*Tsp)-(r/(2*Tsp))^2)^{(1/2)}/(2*pi)/1000$
Chi^2 = 1.58904
Tc   6.3481E-9   ±1.841E-10
Coated - SBR III-Res, f=6.24 mm, Pth = 13.765
QW(ML) Regimes, Time-domain measurement

Ppump/Pth

Relax Osc (kHz)

Coated End - SBR III-Res
—— I=150 mA
C110TM (f=6.24mm), 17% OC
CW-Modelocking

Redacted

Power (dBm)

Wavelength (nm)

Coated End - SBR III-Res
— I=150 mA
C110TM (f=6.24mm), 17% OC
CW-Modelocking

Power (dBm)

Wavelength (nm)

Redacted